REMARKS
ON
THE EFFECT OF RESISTANCE EXERCISE UPON THE CIRCULATION IN MAN, LOCAL AND GENERAL.

BY

T. LAUDER BRUNTON, M.D., F.R.S. Physician, St. Bartholomew's Hospital.
and
F. W. TUNNICLIFFE, M.D., M.R.C.P.

THE extensive therapeutic use of so-called resistance exercises in certain disturbances of the circulation made it, in our opinion, of interest to find out what changes occurred in the circulation in man during and after the practice of these exercises.

Before passing to the description and discussion of our experiments, we may consider briefly what is known of the local and general effects upon the circulation of the contraction of a muscle or group of muscles. Ludwig and his pupils, Sczelkow, Sadler,[1] and Gaskell, were the first to investigate this subject exactly. Two points in Sadler's results are of interest to us in this connection. He found that more blood passed through a muscle when in a condition of contraction than when at rest, and that the most blood in a unit of time passed through a muscle immediately after its contraction. He further found that when a group of muscles were made to contract but were prevented from changing their form, that is, from becoming shortened, considerably more blood passed through them in unit time than passed through muscles thrown into contraction and also shortened.

Gaskell's[2] results in the main confirm Sadler's. The points of difference which are of interest to us are, that in cases of muscles thrown into tetanus for a short time (15 seconds)[3], there often occurred no increase in the rate of flow during the contraction, when the spurt of blood coincident with the commencement of the tetanus had ceased. Further, that the maximum rate of flow was always obtained either directly after the cessation of a tetanus, or in cases of tetanus of relatively long duration at the end of the tetanus. This latter result was constant.

Ludwig and Gaskell point out that in their experiments the muscles were thrown into action by the direct application of electrical stimuli to their nerves, and not by reflex or voluntary stimuli sent down from the spinal cord or brain. Direct stimulation of mixed nerve trunks may possibly have an effect upon the vessels different from reflex or voluntary stimulation, and consequently the results of these experiments on the effect of the direct stimulation of nerves on the flow of blood through the muscles can only hold for reflex and voluntary stimulation to a certain extent, namely, so far as the changes in the circulation are due to pressure on the vessels from without by the contracting muscle, and not to changes occurring in the calibre of the vessels themselves from direct nervous influence.

Mosso[5] found that (1) An arm enclosed in a water plethysmograph diminished in volume during the contraction of the flexors and increased above its normal volume immediately after the cessation of its contraction; and (2) that an increase in the amplitude of the pulsations of the whole arm took place both during and after the contraction of the flexors.

Chauveau and Kaufmann[6] took up this subject in 1892, and made some experiments upon the circulation in the levator labii superioris, and masseter of the horse before, during, and after mastication. They produced mastication by the ingenious method of simply putting oats in the horse's mouth. Those of their conclusions which are of interest to us are as follows: The circulation through muscles in a condition of physiological activity is under the influence of two opposing factors, namely—(1) the vaso-dilatation which accompanies contraction favours the passage of blood through them; (2) the shortening of the muscle, which, by compressing the vessels, offers a mechanical obstruction to the circulation, and hence renders the flow intermittent. During shortening the muscle becomes empty of blood; during the subsequent relaxation it becomes full of blood.

Coincidently with the contraction of the masseter there occurred a rise in blood pressure in the muscular vein and a fall in that in the muscular artery, showing that the blood was flowing more freely from the artery into the vein; at the same time a rise occurred in the blood pressure in the carotid. These experimenters were the first to demonstrate the changes occurring in the circulation through muscles thrown into contraction by reflex stimulation as opposed to direct electrical stimulation of their motor nerves. The results of these experiments in the main confirm the results of Ludwig and his pupils. It must be remembered, however, that the conditions in the experiments of Chauveau and Kaufmann are not so simple as they at first sight appear, since as a result of the mastication of oats a number of other vascular reflexes would probably occur—notably a dilatation of the vessels going to the salivary glands.

Marey[7] found that the pressure in the carotid of the horse fell 6 mm. immediately after a run of ten minutes, in spite of greatly-increased cardiac frequency; subsequently it rose 7 mm. above its original height. He[8] also found that if, during the taking of a radial sphygmogram, the subject was directed to contract energetically the muscles of the thighs and legs, and at the same time to avoid holding the breath, the base line of the sphygmogram rose considerably. He quotes this latter result as being evidence that there is a considerable obstruction to the circulation—that is, a considerable increase in peripheral resistance, during the contraction of muscles. The results of these experiments of Marey, put shortly, are that during considerable muscular exercise the general blood pressure is raised, but falls below the normal after the exertion is over.

Oertel,[9] von Basch, Maximowitsch and Rieder[10] observed a considerable rise in the general blood pressure follow muscular exercise. The more recent results of Hallion and Comte,[11] and Bloch[12] are in the main in accordance with those of Oertel.

From the above brief summary it will easily be seen that the results obtained are, to a very great extent conflicting. This in all probability depends upon the amount of exercise, gradual and excessive exercise having a different effect on the general blood pressure. Further, as far as we have been able to ascertain, no estimations of the general blood pressure have been made while the muscles were actually contracting during exercise, Oertel's observations having been made during the pauses. In the experiments we are about to describe the exercise was slight and exceedingly gradual, no change in the frequency and practically none in the depth of the respirations being produced during it.

Method.—The instrument employed to measure the blood pressure was the sphygmomanometer of Mosso.[13] All estimations before, during, and after the exercise were made in the erect position. The arms were fixed by means of plaster-of-paris into boxes, which were applied to the arms of the sphygmomanometer. By this means the subject was kept in the same position during the whole experiment, which was thus rendered continuous.[14]

Control experiments were made with a view of ascertaining what changes occurred in blood pressure, pulse, and respiratory frequence in a man standing in the position necessitated by the experiment for three hours. At the end of the second hour a slight diminution in pulse frequency invariably occurred (from six to ten beats per minute). Respiratory frequency remained unaffected. In about half the experiments a diminution of blood pressure as measured by the sphygmomanometer also occurred. This never amounted to more than 5 mm. of mercury, and never occurred till after the second hour. The results of these experiments may be taken as indicating the slight extent to which the circulation in man is affected by the fatigue of standing for three hours.

The following protocol may be regarded as typical of the results of these experiments: Man of average height, aged 30, weight 10 st., took his ordinary dinner at 12.30 P.M., and slept after it. At 2.30 P.M. he went into position on the experimental platform; his arms were fixed in the boxes and his fingers in the sphygmomanometer.

3.00.—Pulse 96, respirations 16, pressure 80 mm. mercury.
3.30.—Pulse 96, respirations 16, pressure 80 mm. mercury.
4.00.—A bag of shots weighing 800 g. was placed round left ankle, and one weighing 900 g. round right ankle.
4.05.—Slow movements begun. Movements consisted in slowly flexing the legs on the thighs and the thighs on the trunk.

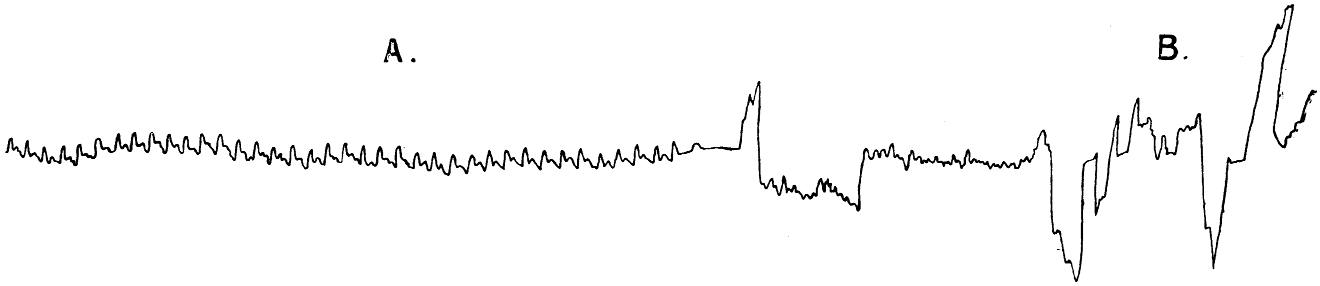


Fig. 2.—Curve A is the sphygmogram obtained with the muscles at rest; curve B is the tracing obtained during

4.20.—Pulse 92, respirations 16, pressure 90.
4.35.—Pulse 92, respirations 16, pressure 80, movements stopped.
5.00.—Pulse 84, respirations 16, pressure 74.
5.05.—Pulse 84, respirations 16, pressure 70.
5.20.—Pulse 84, respirations 16, pressure 80.
Experiment discontinued.

The results of this experiment will be seen more readily by a glance at the accompanying curve (Fig. 1).

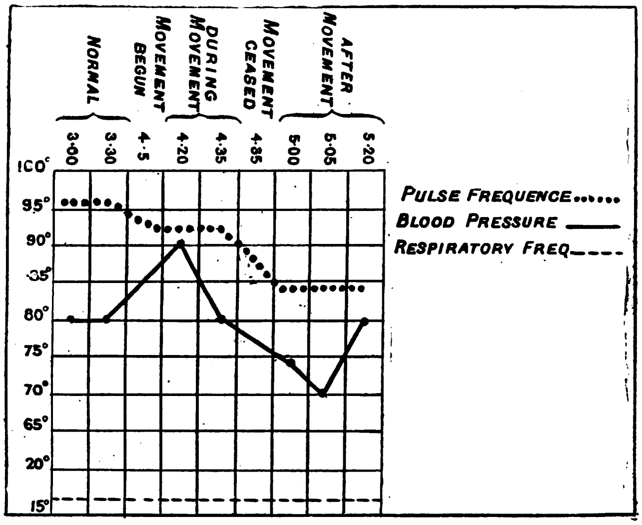


Fig. 1.

Coincident with the commencement of movement a slight diminution in pulse frequency took place, and a considerable rise of blood pressure. During, however, the second half of the movement the blood pressure fell to its original level and the pulse frequency remained the same. After the cessation of the movements the blood pressure fell, and at first also the pulse frequency; this latter, however, remained constant before the blood pressure had reached its lowest point, which it did half an hour after the cessation of the movements. Three-quarters of an hour after the cessation of the movements the blood pressure had again risen to its former level.

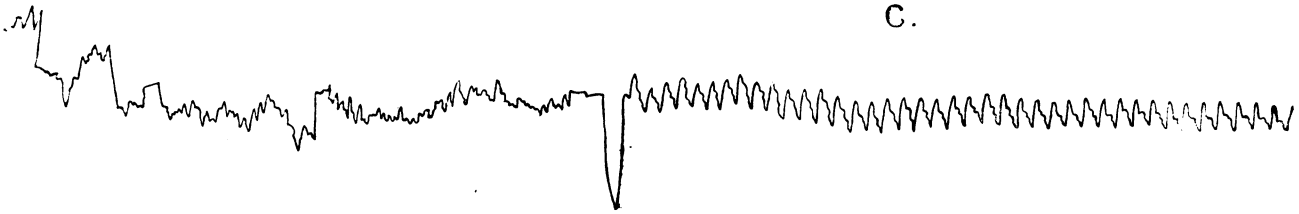
In the above experiment it is to be noted that no change took place in the frequency of the respiration. Curves taken with a Marey's double pneumograph showed also that a very slight increase in the depth of the respiratory movements took place, and that the pulse frequency fell fairly steadily from the beginning to the end of the experiment. In some of the experiments a slight increase in pulse frequency occurred coincidently with the initial rise in blood pressure. In our experiments we always observed a rise of pressure varying from 5 to 10 mm. of mercury during the first stage of the exercises, whether the pulse frequency remained the same, was increased or diminished. The pressure rarely fell below the normal, the minimum pressure being registered from fifteen to thirty minutes after the cessation of the movements.

Before attempting to explain these results it will be better to consider the local changes which occur in the muscular arteries subsequent to muscular contraction. The muscle which we chose for this purpose was the gastrocnemius. The subject was placed in the supine position, with the leg slightly raised. At a given moment he was directed to extend the foot by contracting the muscles of the calf, the movement of the foot being the while resisted, so that very little if any shortening of the muscles occurred. The muscles were kept in a condition of contraction for the desired time, at the expiration of which time the subject was directed to desist. The apparatus which we used to obtain the following tracing was designed by one of us (Tunnicliffe) in conjunction with Professor Mosso, of Turin, and has received the name of myosphygmometer. It will be fully described elsewhere; suffice it to say here that we regard the above tracing as a muscular sphygmogram. This sphygmogram, which for the sake of convenience has (Fig. 2) been split up into three parts (A, B, C) was taken continuously, the sphygmomanometer being kept in position during the entire experiment. The changes in the pulse occurring subsequently to contraction are best seen by reference to these curves (Fig. 2). Curve A requires no explanation. It will be seen that both the respiratory and vascular oscillations of pressure are manifest in it, and hence it may be taken as a sensitive index of the changes occurring in the vessels.

Concerning the Curve B, or the one taken during contraction, we are at present unable to make any exact statement with regard to the condition of the vessels during this period. It is possible that the fibrillar twitchings which occur when the belly of a muscle like the gastrocnemius is thrown voluntarily into contraction may be responsible, probably are in some part, for the masking of the arterial pulsations during contraction. Another, and to us a more probable explanation, is that the result is in the main due to a partial occlusion of the intramuscular arteries and arterioles during the period of contraction. This explanation would be in accord with the observations of Ludwig and Gaskell, that during a short tetanus, after the first jet-like rush of blood, the flow from the efferent vein may fall to practically *nil*, or, in other words, the vessels may have their calibre practically occluded.

With regard to change in the sphygmogram after contraction, there is much less room for uncertainty. If we examine the post-contraction sphygmogram, and compare it with the sphygmogram taken before contraction, we shall see that although the pulse frequency has remained practically the same, the pulse itself has become considerably altered. The pulsations are larger, nearly double their former size, and the relative position of the dicrotic notch is altered. The inference one can draw from this is that the arteries have increased in diameter, and are relatively fuller than they were before the contraction. If we now direct our attention to the end of the curve we shall see that the last few pulses which are registered are almost identical with those occurring before the contraction. If we reckon this in time it means that a contraction lasting one minute produces an arterial dilatation lasting half a minute.

Having considered the local and general changes in the circulation in man consequent upon the practice of resistance exercises, the question which naturally arises is how far the local changes explain the general ones. There can be little doubt that the fall in general pressure which always follows the exercises is in great part due to the dilatation which occurs in the peripheral muscular arterial area. A considerable diminution in peripheral resistance being thus produced; exercise acting in this way similarly to a vaso-dilator such



the contraction of the gastrocnemius; curve c that immediately ter the cessation of the contraction

as nitro-glycerine, etc. The rise in general pressure which takes place is less easy to explain. It is probably in part due to reflex cardiac stimulation and in part to the diminution in calibre of the peripheral muscular arteries which occurs during the shortening of the muscles which are called into play. The last of these factors is most probably far the most potent. This initial rise in pressure can be considerably diminished by making the exercises very slow, but we have never succeeded in abolishing it entirely. The fact that even during the exercises, after they have been continued for some time, the pressure returns to its normal level, and may even sink below it, seems to point to the conclusion that by the contraction of a muscle some substance is produced which exerts a vaso-dilating influence, and as the amount of this substance increases its nett result is to overcome the diminution in arterial calibre which is mechanically produced by the shortening of the contracting muscles.

The conclusions which we are able to formulate from the above experiments fall under two heads—(I) Physiological, (II) Medical.

(I) Physiological. (*a*) Locally, gentle exercise is followed by a dilatation of the muscular arterioles with an increased flow of blood through them. This is shown by the fact that after the contraction is over the pulsations in the muscle have a greater amplitude, that is, there is a greater distance between the crest and hollow of each pulse wave than before the contraction. As these alterations in the circulation are purely local, the heart remaining the same, they can only be due to a local dilatation of the arterioles in the muscle, allowing them to empty themselves more rapidly during the cardiac diastole.

(*b*) Generally, the effect of exercise so gentle as to cause no hurry in the respiration and no increased frequency in the pulse on the general blood pressure is that during the exercise itself the pressure first rises above the normal, but begins to fall, even during the continuance of the exercise, continues to fall, so that at the end of the exercise it has usually reached the normal. After cessation of the exercise the pressure continues to fall. The pressure after the exercise may remain subnormal for half an hour or longer; after the expiration of this time it gradually rises again to its initial height.

These results may at first sight appear to differ from those of Oertel, who found that a rise in general blood pressure invariably followed muscular exercise. We believe that the difference between his results and ours depends upon the amount of exercise taken being different in the two cases. In his experiments the amount of exercise was sufficiently great to cause considerable strain. In one case, for example, the exercise consisted in making an ascent in forty minutes for which an hour was usually reckoned. Although he notes that no difficulty in breathing occurred, yet the respiration must certainly have been quickened.

If we compare the results of our experiments just mentioned with those which we found to follow massage,[15] we notice that the primary rise of blood pressure upon exertion is greater than that caused by massage, but that the subsequent fall is both greater and of longer duration.

(II) General medical conclusions. (*a*) In cases where the heart is very feeble, so that the primary rise of blood pressure caused by even gentle exercise may interfere with its action, massage is the mode of treatment best adapted for restoring the circulation. (*b*) That when the heart is sufficiently strong to bear the increased resistance presented to it by the primary rise of pressure occurring during exercise, gentle exercise is preferable to massage, inasmuch as the subsequent diminution of resistance is greater in amount and of longer duration. (*c*) The difference between our results and those of Oertel affords a scientific basis for the practical rule which has been found so advantageous at Nauheim, namely, that the exercises shall not be carried to such an extent as to cause any acceleration of breathing on the part of the patient.

We desire to express our thanks to Professor Mosso, of Turin, for allowing some of the above experiments to be done in his laboratory and also for his kind help in them; also to the Scientific Grants Committee of the British Medical Association for a grant towards the expenses of this research.

REFERENCES.

[1] Ludwig's *Arbeiten*, 1869. p. 77. [2] Ludwig's *Arbeiten*, 1877, p. 45. [3] *Ibid.*, p. 77, *et seq.* [4] Ludwig and Segellion, *Heub. v. Pfeiffer's Zeitschrift*, 1863, vol. xvii, 106, 122. [5] *Sulle Variazioni locali del polso nell' antibraccio del uomo*, Torino, 1878. [6] *Archiv. de Phys.*, 1892, p. 279. [7] *La Circulation du Sang*, Paris, 1881, p. 343. [8] *Op. cit.*, p. 525. [9] *Handbuch der allgemeinen Therapie der Kreislaufs-Störungen*, Leipzig, 1891. [10] Untersuchungen über die durch Muskelarbeit und Flussigkeitsaufrahme bedingten Blutdruck-Schwankungen, *Deutsch. Archiv f. klin. med.*, Band, xlvi. [11] *C. R. Société de Biologie*, x serie, iii, 906. [12] *Loc. cit.* [13] *Archives Italiennes de Biologie*, xxiii Fasic. 1895. [14] Further details as to method with regard to the estimation of general blood pressure, and the local arterial change will be given elsewhere. [15] *Journal of Physiology*, vol. xvii, No. 5.

THE ROENTGEN RAYS AND THE FLUOROSCOPE AS A MEANS OF DETECTING SMALL, DEEPLY-PLACED STONES IN THE EXPOSED KIDNEY.

By E. HURRY FENWICK, F.R.C.S.,
Surgeon to the London Hospital, Surgeon to St. Peter's Hospital for Urinary Diseases.

No renal operation is probably safer, easier, or more brilliant in its after-results than is the removal of an oxalate of lime stone from the surface of the kidney. The finger of the operator detects the stone in the cortex directly the organ is exposed; his finger-nail is sufficient to free it, and the patient is at once relieved, without danger, from a source of suffering which may have crippled him for years.

Not less easy, but not quite so smooth in its convalescence, is that case in which the stone is at once felt in the undistended pelvis, or that in which the stone is discovered on opening a dilated pelvis.

These three classes do not require skill—merely cleanliness, gentleness, and care. The real crux of renal surgery is encountered when we have to deal with a small prickly calculus imbedded in the end of a lengthy calyx of an undilated pelvis (Fig. 1 c). To detect such a stone and to remove it with but little damage to the delicate tissue of so vital an organ as the kidney is almost impossible with our present methods. The operator, moreover, is often haunted by the knowledge that certain forms of unilateral, non-somatic kidney disease (for instance, the granular kidney and the large white kidney), if locally inflamed or irritated by pyramid-chokage, simulate stone very closely; and if a diligent search is rewarded only by profuse hæmorrhage, he hastily concludes that his diagnosis of stone is faulty, and that he is dealing with a de-